



Red Hill Bulk Storage Facility: Groundwater Flow Hypotheses Testing

Groundwater Model Working Group (GMMWG) Meeting October 18 & 19, 2021

Prepared October 15th, 2021

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Technical Presentation Background



Examples of Lessons Learned, their Evaluation, and Potential Implications

- Previous presentations describe some technical concerns about the Navy groundwater models
- Some lessons have been learned from review of these models and the accompanying CSM document
- Two examples are presented:
 1. Parameterization methods and the clinker model
 2. Evaluating potential sources of water to wells
- These are demonstrated using local-scale calculations



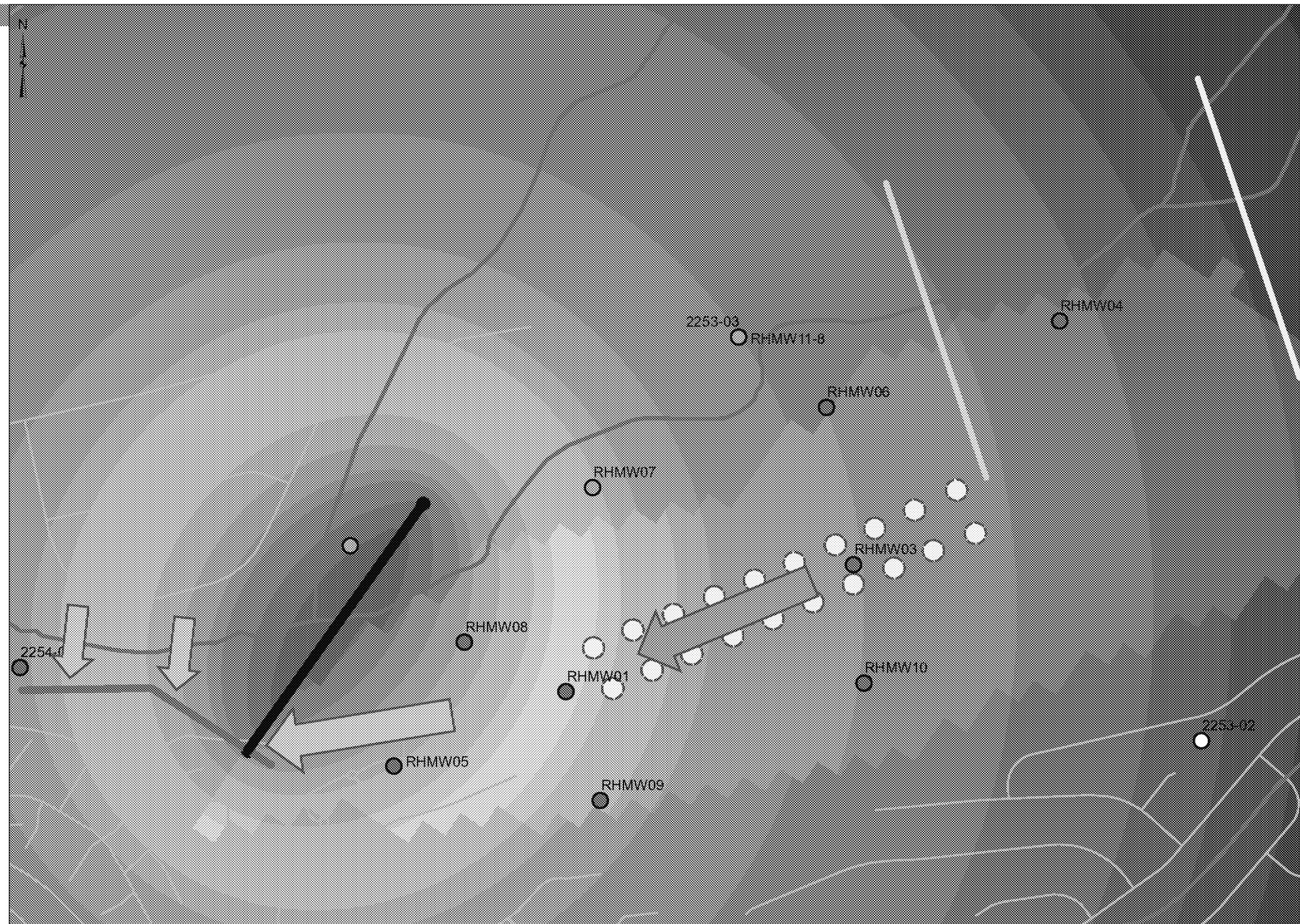
Example 1(A): Basalt Parameterization Methods

- The “clinker model” illustrates patterns and provides improved fit statistics for observations but overwhelms directional anisotropy important to transport and capture:
 - Capture at high flows may overwhelm this effect - i.e., *EPM with direction anisotropy is representative*
 - Capture at low flows is modeled as deriving from large clinker but would in reality extend preferentially along true but unknown clinkers - i.e., *EPM with direction anisotropy is not representative*



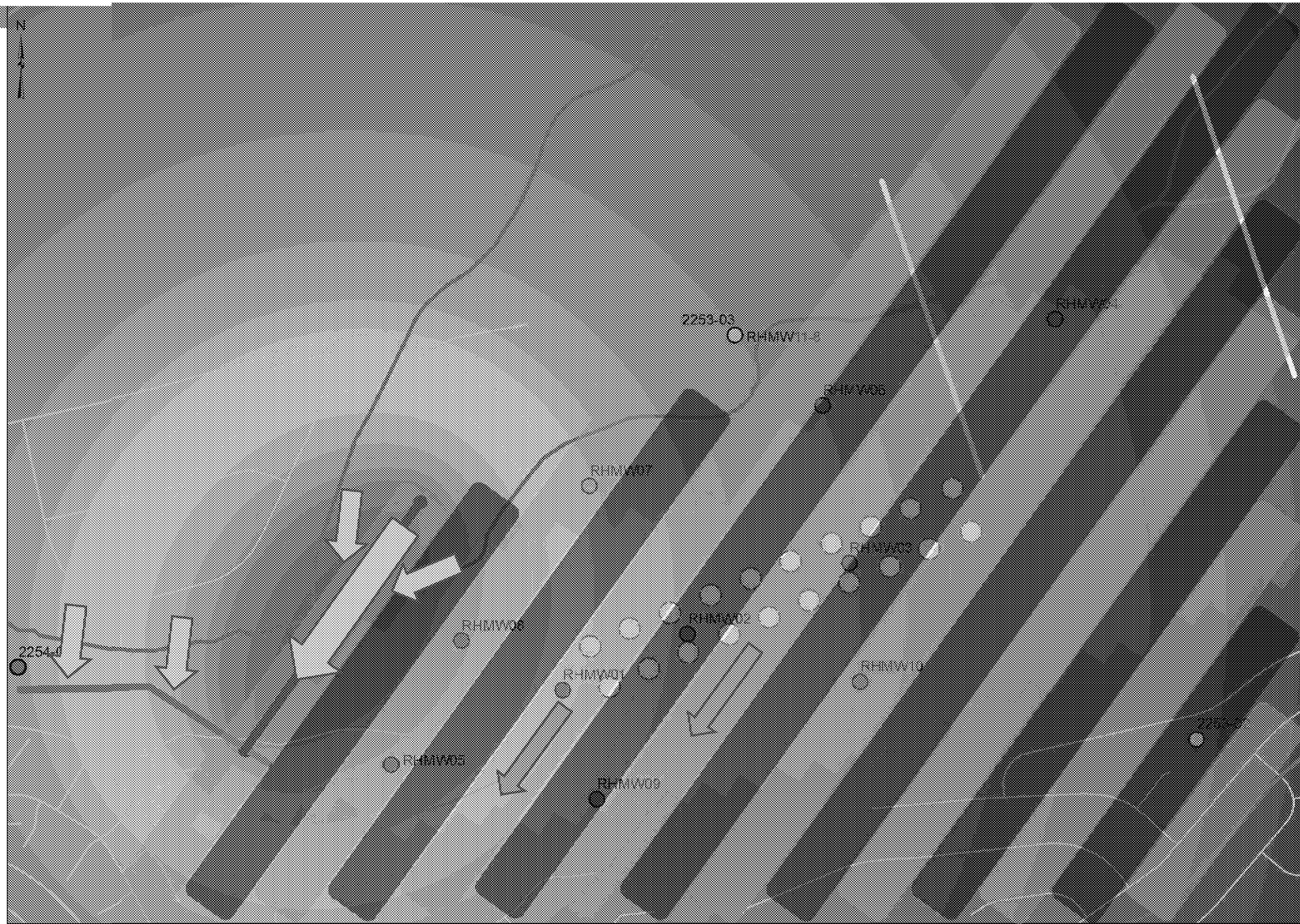
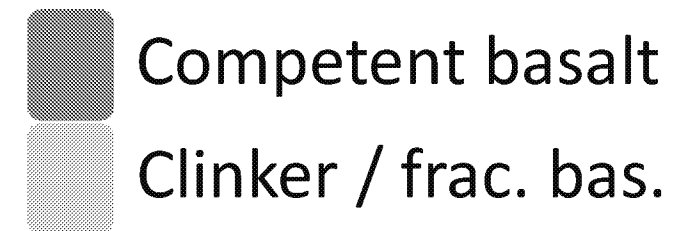
Example 1(A):

- Drawdown pattern calculated using analytic element approach assuming longitudinal drain
- Superimposed Navy clinker model zonation



Example 1(A):

- Hypothetical flow arrows reflect combined effect of pumping and aligned connectivity.
- Sources of water to RHS may include vertical flow.



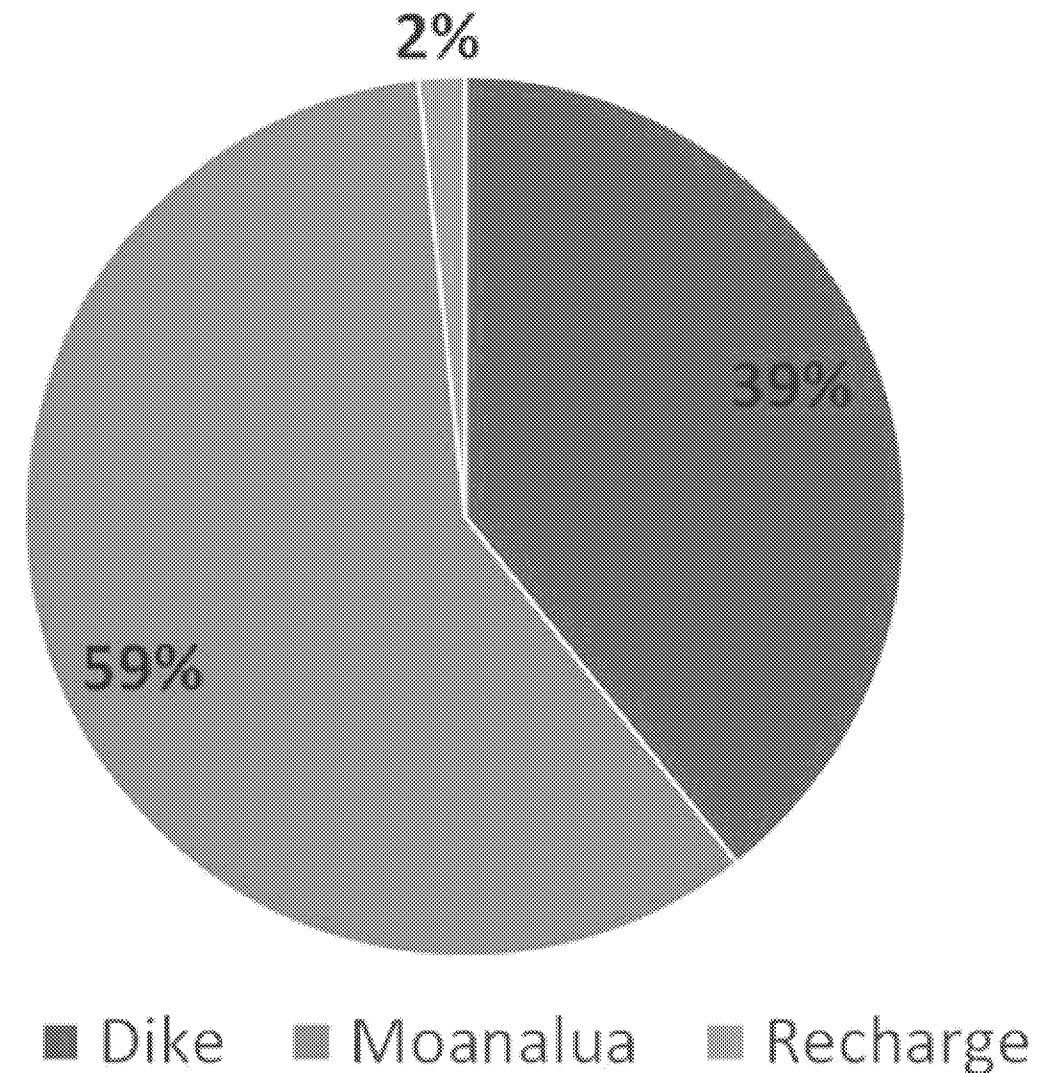
Example 1(B): Containment, Capture, and Source(s) of Water

- The terms “*source of water to wells*” and “*capture*” appear in different contexts:
 - The water-budget context addresses water-budget components affected by pumping but it does not address pathways.
 - The transport context focuses on flow paths, identifying where water discharging at a well entered the system. It relates to the “Zone of Contribution”.
 - The region of hydraulic containment is a 3D surface that separates water that will ultimately be recovered by the well from water that will not.
- Improved understanding of the water budget aspects of “*sources of water to wells*” improves understanding in the transport context.
- Mixing analyses can identify sources and sinks of water, with implications for the hydraulic containment (or *capture zone*) developed by RHS.



Why Mixing Analyses?

- Mixing analyses enable a flow model to be used to calculate contributions to pumped wells of various potential sources such as recharge and boundaries.
- Output from these calculations can be used as mixing proportions to evaluate geochemical data, enabling this information to be used to understand flow patterns.



Technical Presentation Outline

- Technical Approach
- Example Applications
- Discussion
- Next Steps for AOC parties



Technical Approach



Conceptualization and Development – 1:

Principal Study Questions (PSQs) and Hypotheses

- Are observed conditions consistent and plausible:
 - Low gradients, high transmissivity, and elevated chlorides?
 - Does upwelling contribute chlorides and other constituents to groundwater?
 - Is there evidence for compartmentalization and what role does this play?
- Can these conditions demonstrate reasonable correspondence to locally-measured pumping effects and estimate capture?



Conceptualization and Development – 2:

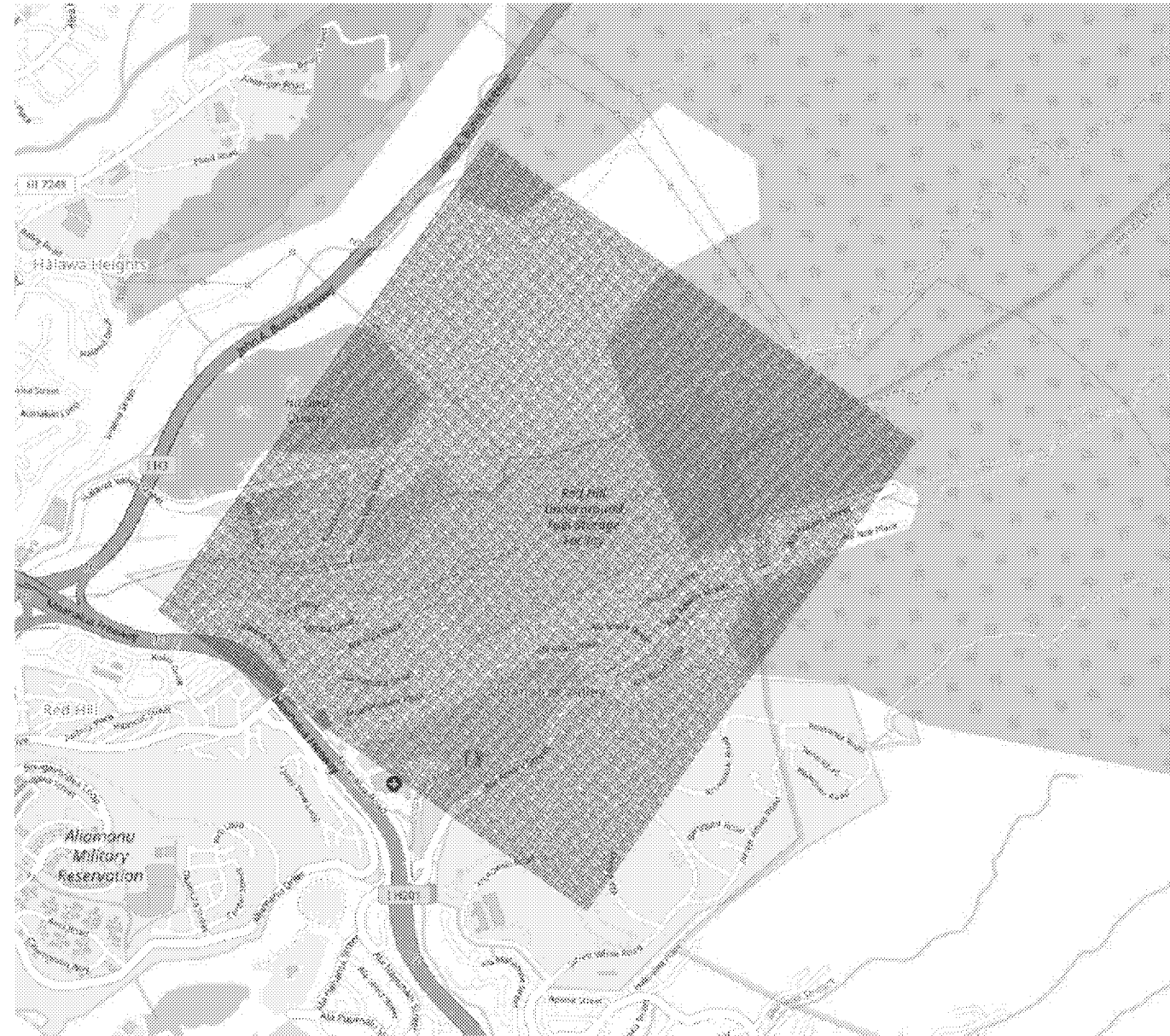
Development

- Local-scale flow-conserved framework that is sufficiently complex to evaluate PSQs but simple enough to be quickly modified and executed:
 - Layering based on best-available dip & strike information
 - Structure-imitating basalt parameterization using parameter values consistent with other sources of information
 - Boundaries emphasizing local-scale data and regional-scale analyses
 - Reasonable and unbiased calibration.
- Intent is to provide lessons-learned or other information for quantitative or qualitative use within the Navy model(s).



Analysis Domain and Boundaries

- Rotated grid with cells of side-length 30ft x 30ft (9m x 9m)
- 15 layers with a 3° dip
- Adjustable combination of GHB and CHD boundaries
- RHS represented as a “drain” due to uncertain flow rates

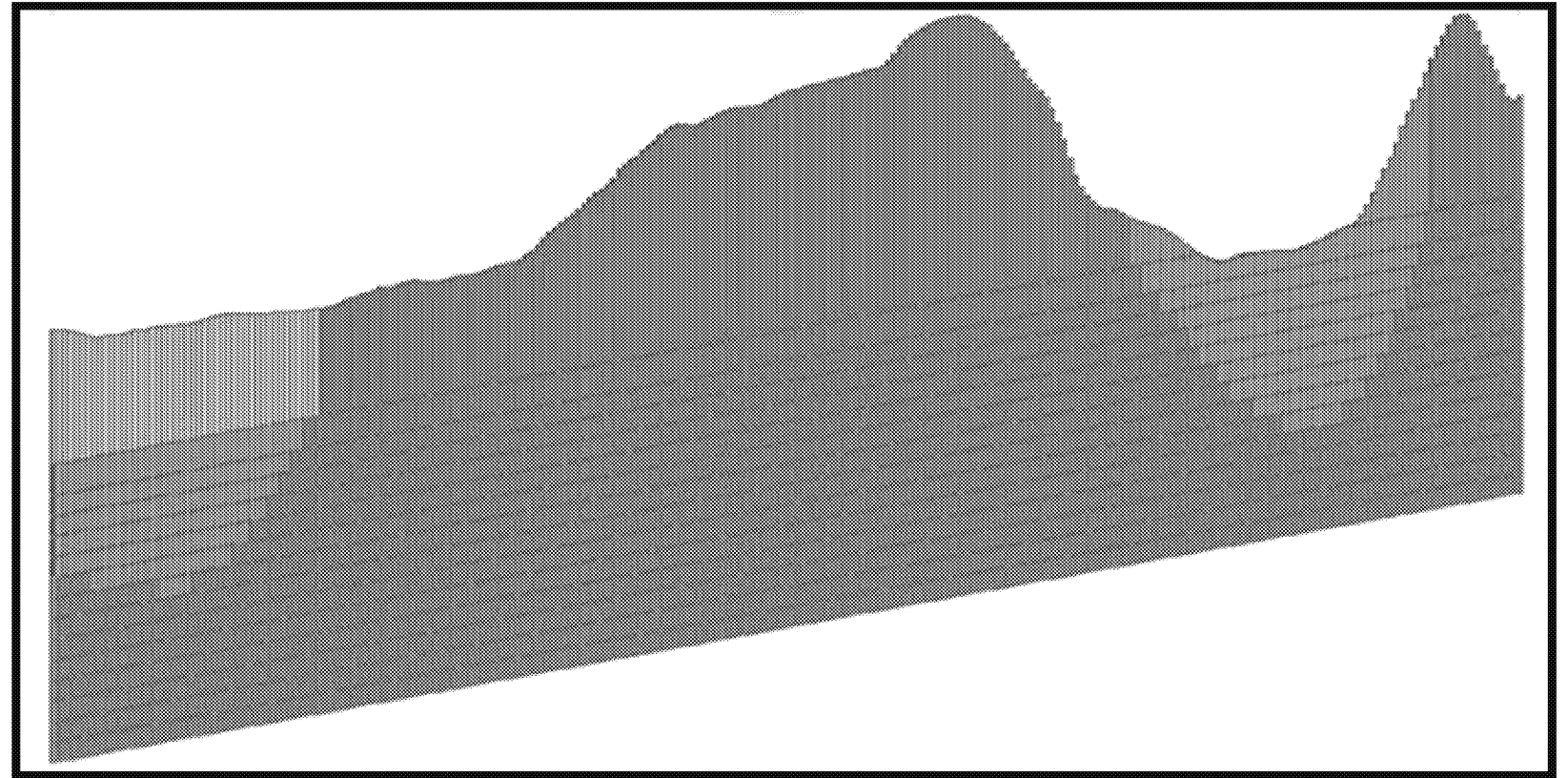
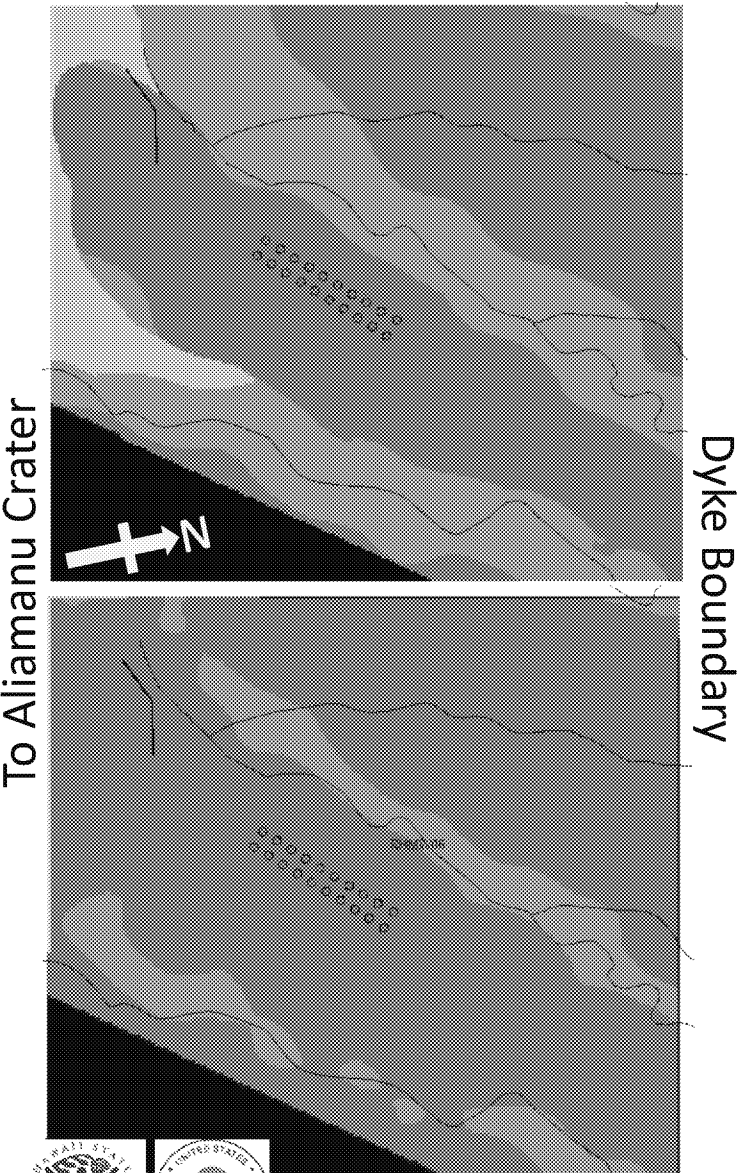


Material Types

- Basalt:
 - All cells initially set to basalt
 - Subsequently, saprolite and caprock/tuffs were emplaced
- Saprolite – two representations (shallow, deep):
 - Conductivity assumed to be low but not impermeable
- Caprock / tuffs:
 - Outline used to convert encompassed cells in top layer
 - Testing evaluated sensitivity of assumptions with increasing depth



Basic Material Types



Basalts



Saprolite



Caprock

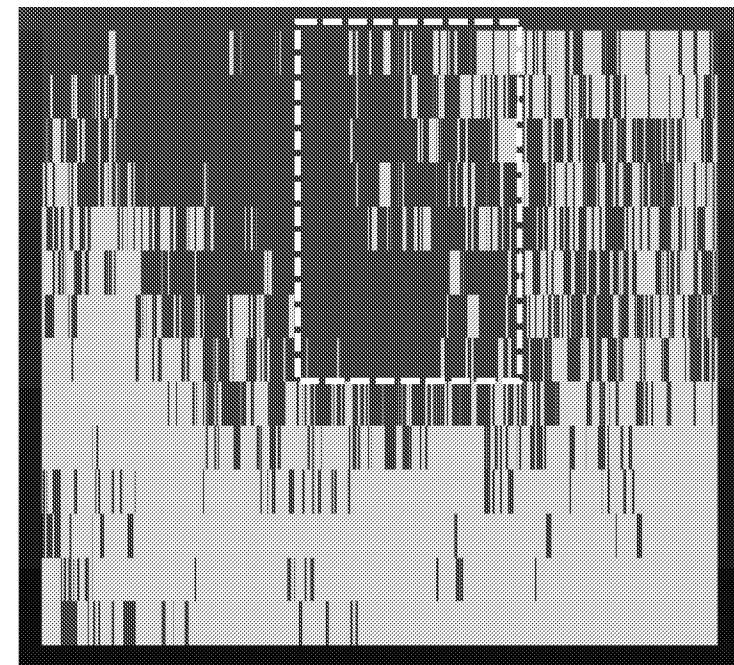
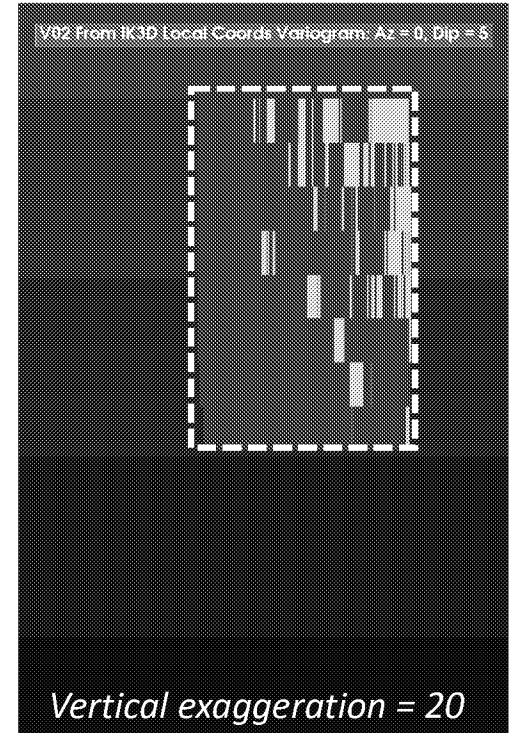


Basalt Parameterization –Scale and Vertical Paths

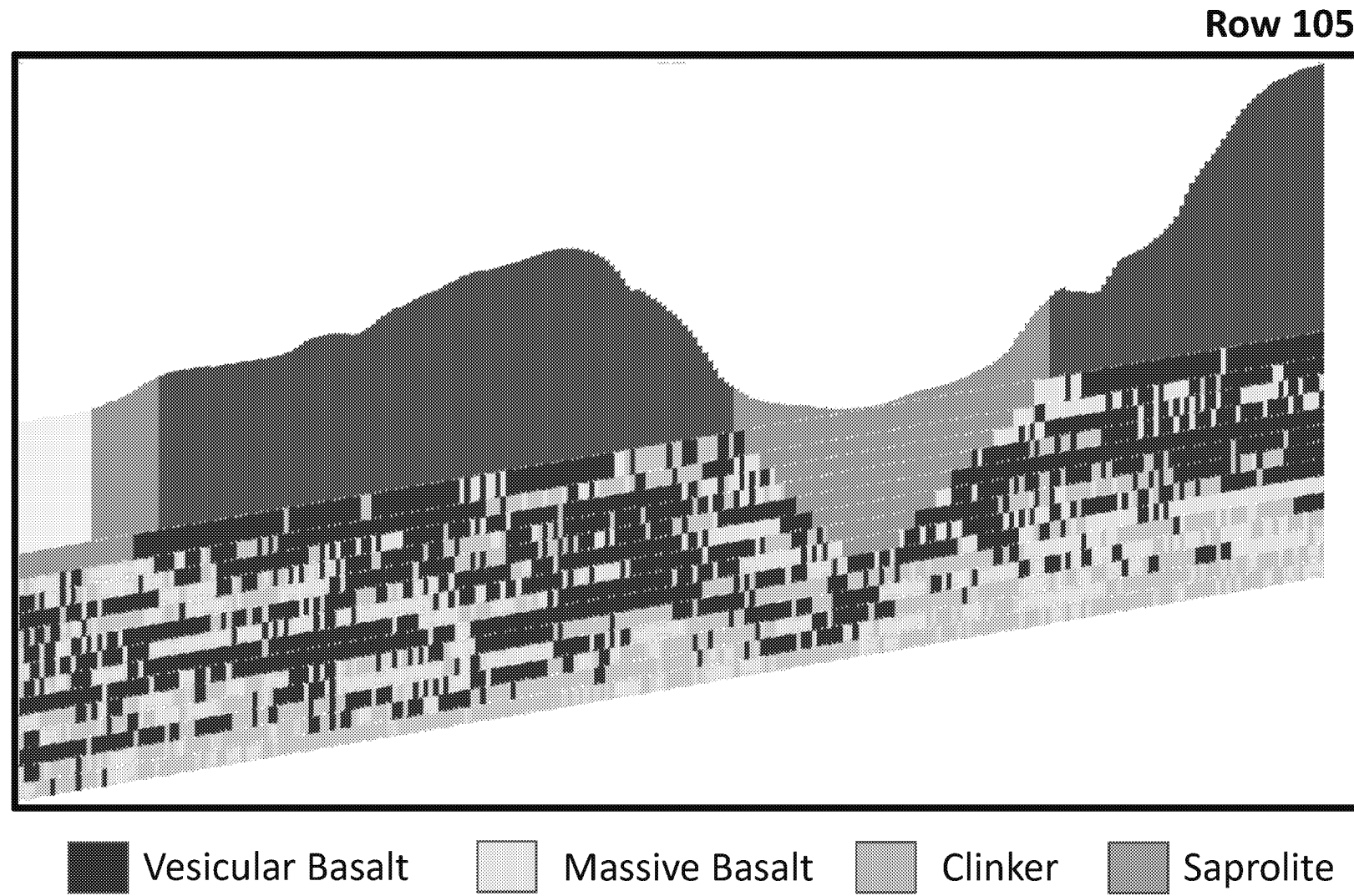
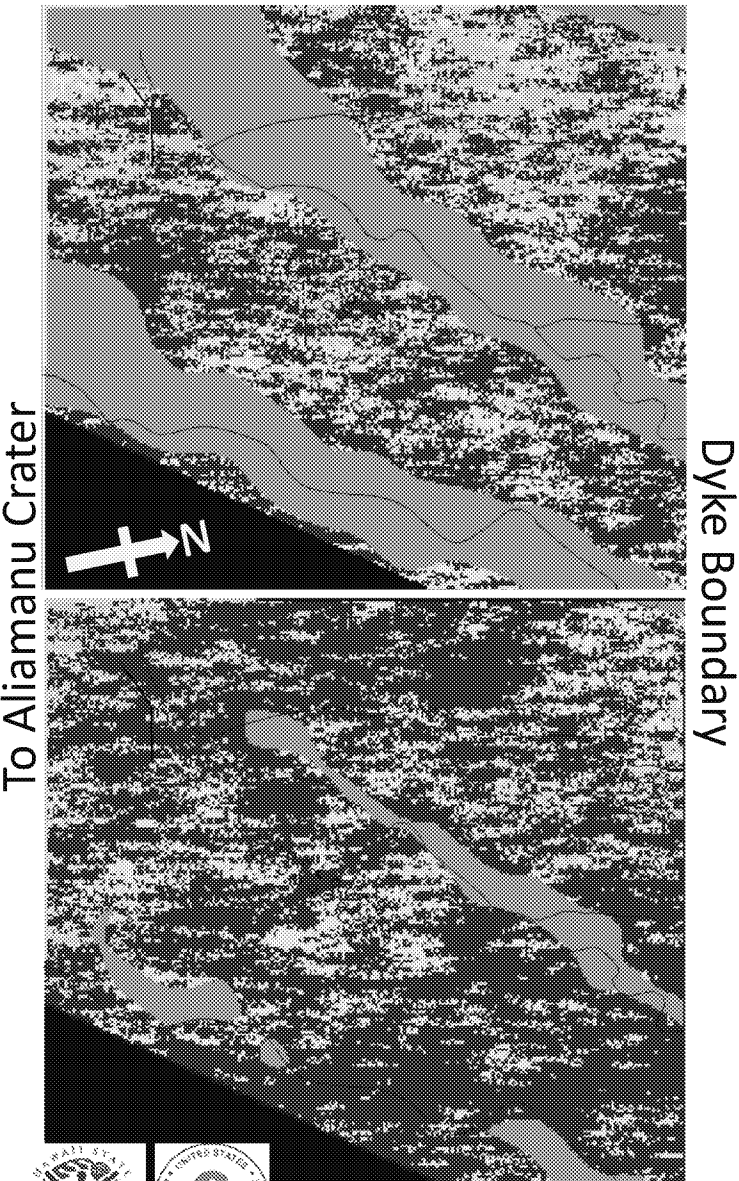


Basalt Parameterization

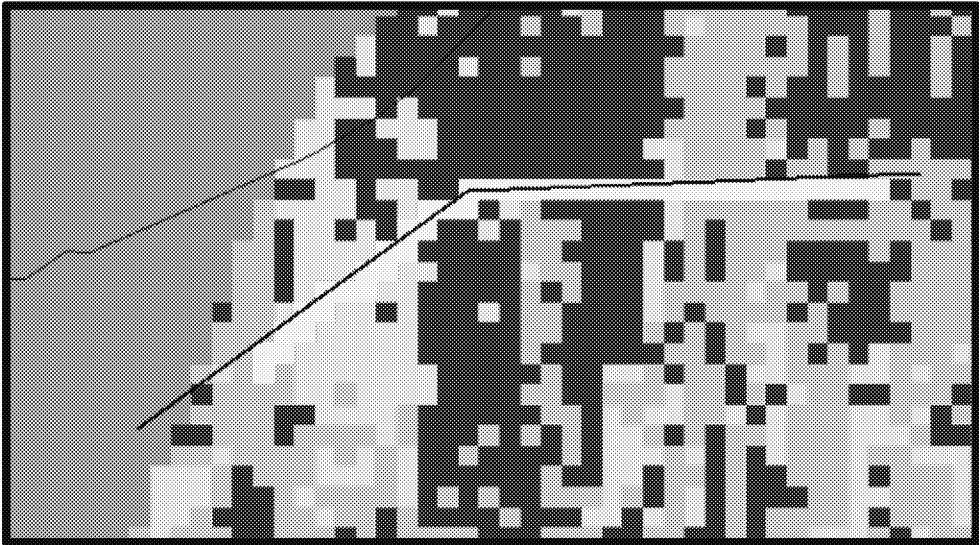
- Indicator kriging [IK3D] and realizations [SISIM] to extend proportions and correlation scales to full domain
- Area-of-overlap indicates consistency
- Conditioning to data-rich barrel logs vs application to data sparse saturated zone
 - Well log and RHS tunnel data are ultimately used



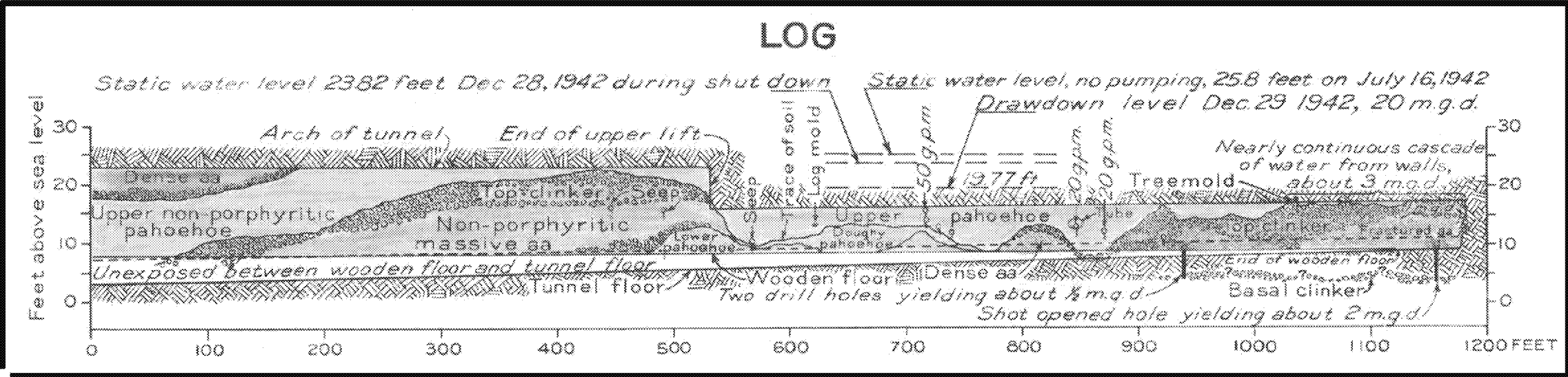
Incorporation Into Local Model (L2, L8 Shown)



Incorporation of RHS Tunnel Lithology

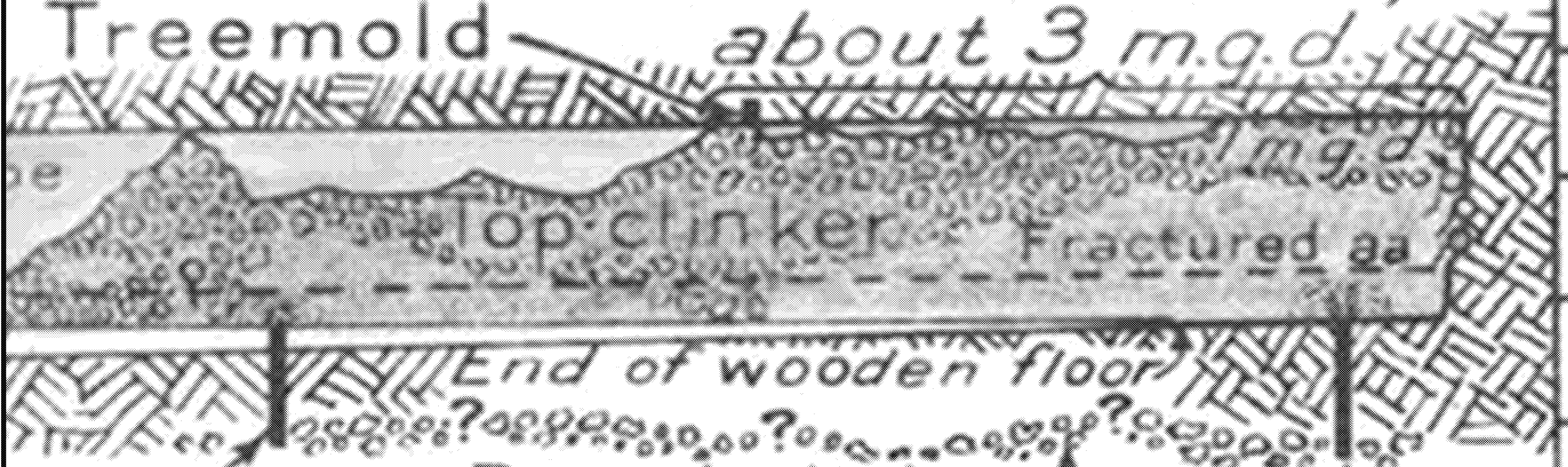


- Vesicular Basalt
- Massive Basalt
- Clinker Zone
- Saprolite



Nearly continuous cascade
of water from walls,

Treemold about 3 m.g.d.



Top clinker Fractured aa

End of wooden floor

Basal clinker

hole yielding about 2 m.g.d.

Example Applications



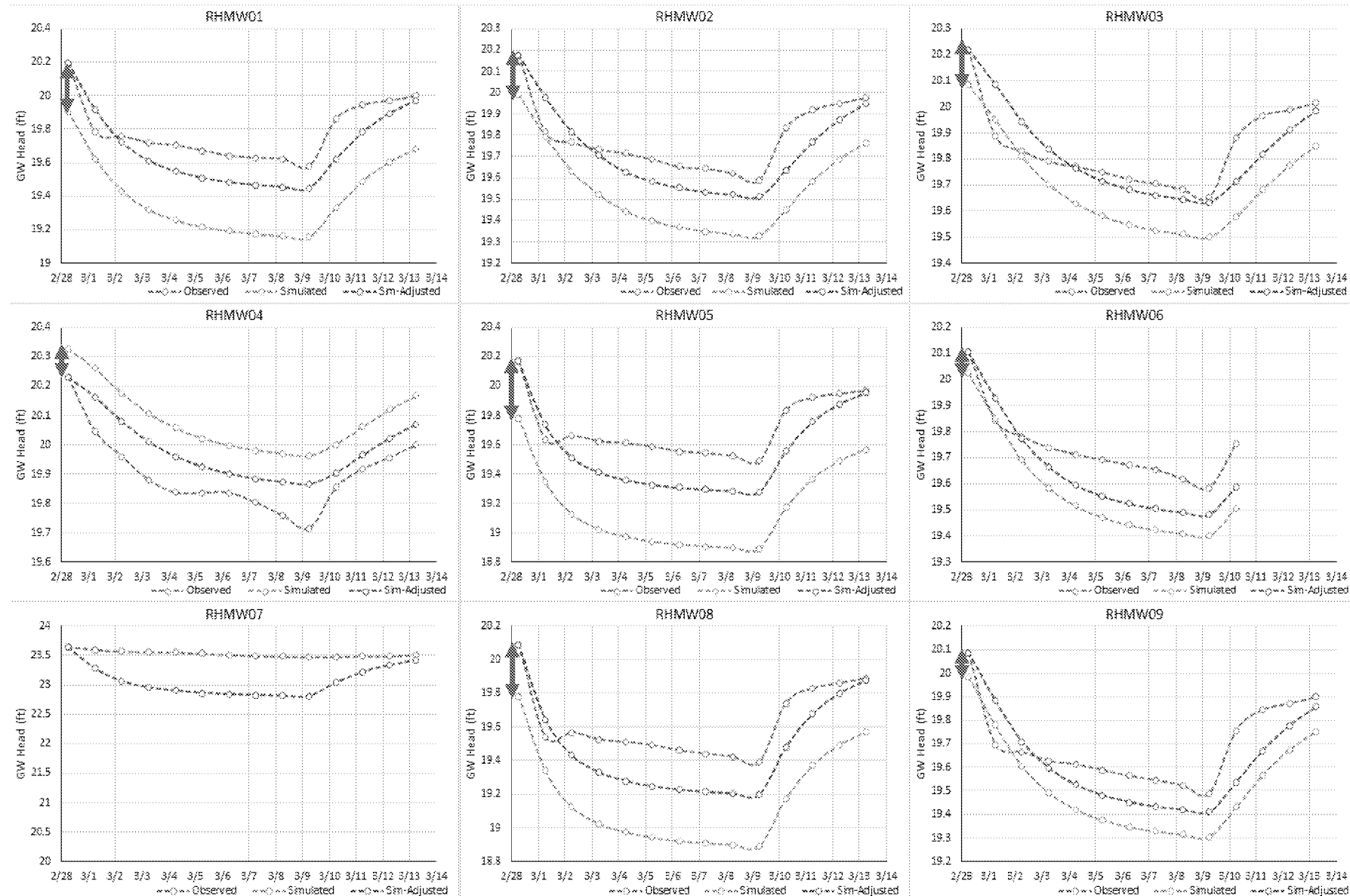
Example Applications - Overview

1. Transient flow calibration
2. Forward particle tracking
3. Unit source mixing



1. Transient flow calibration - heads

- Plots shown for the heterogeneous three-material realization



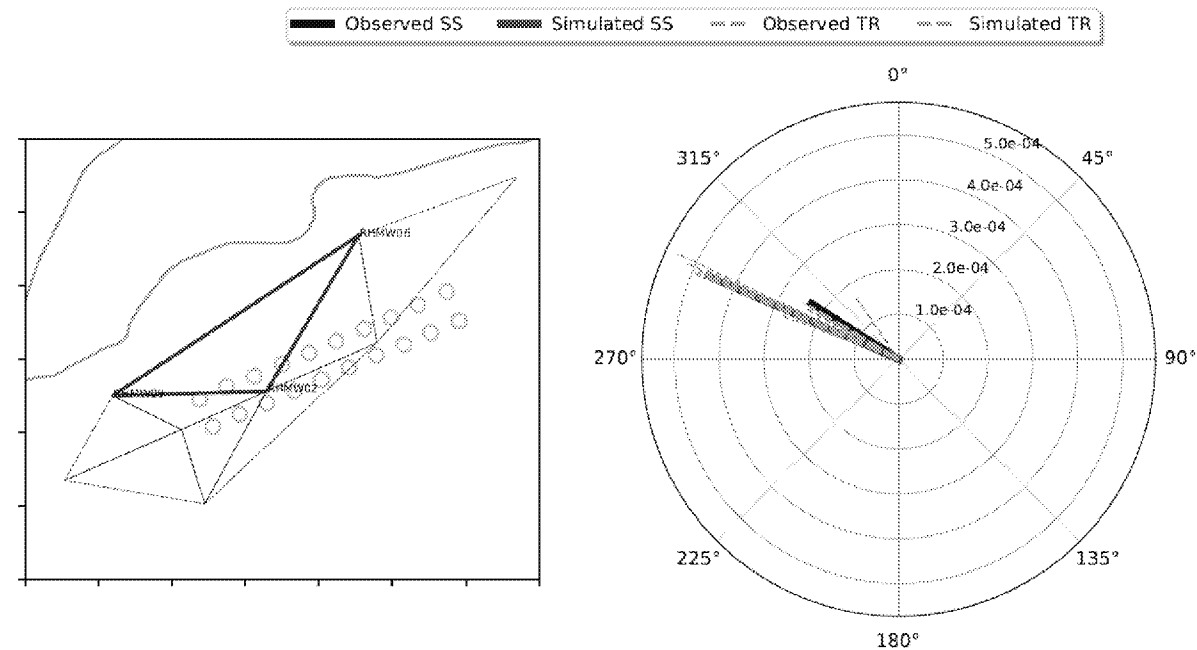
1. Transient flow calibration – gradients (TPG)

- All triangles including wells on south side of RHBSF show southward direction
- All triangles not including wells on south side of RHBSF show northwestward direction
- Recall that in this setting, "apparent" gradients do not necessarily indicate actual flow direction, due to anisotropy
- It is currently challenging to consistently represent the local "saddle": *Is it real? Is it meaningful?*



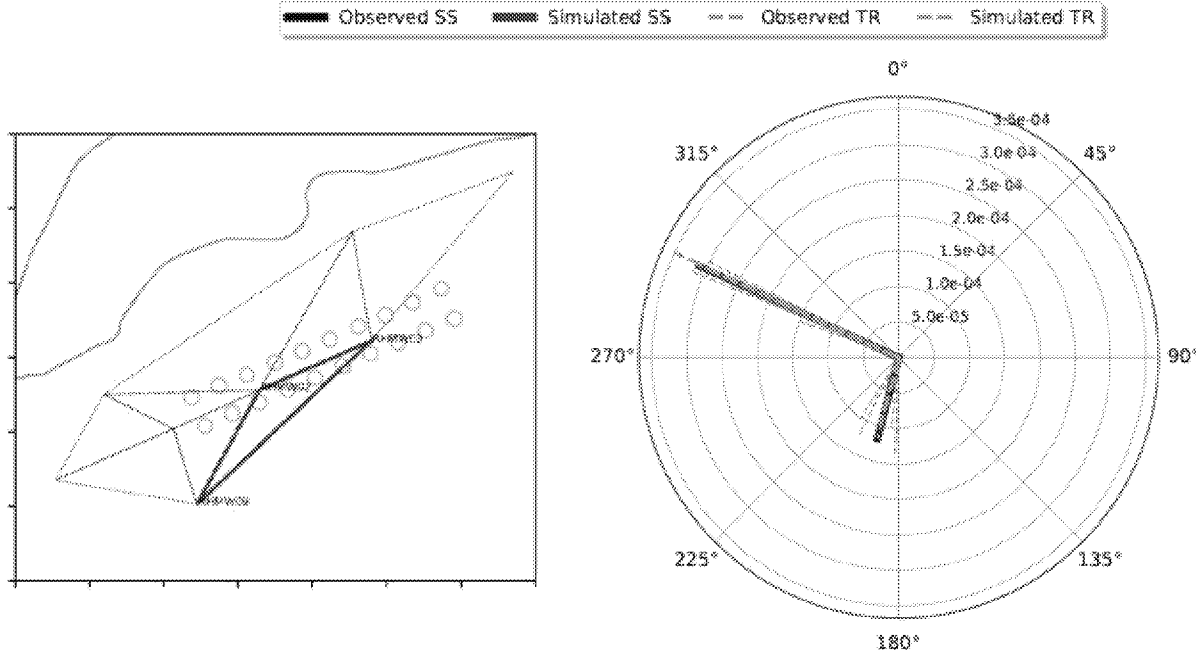
1. Transient flow calibration – gradients (TPG)

Three-Point Gradients (Observed vs.Simulate) at Triangle 1



	Observed	Simulated
Number of Days	11	11
Minimum Azimuth	295.8	290.5
Maximum Azimuth	325.3	295.5
Minimum Magnitude	1.6e-04	2.2e-04
Maximum Magnitude	2.9e-04	5.5e-04

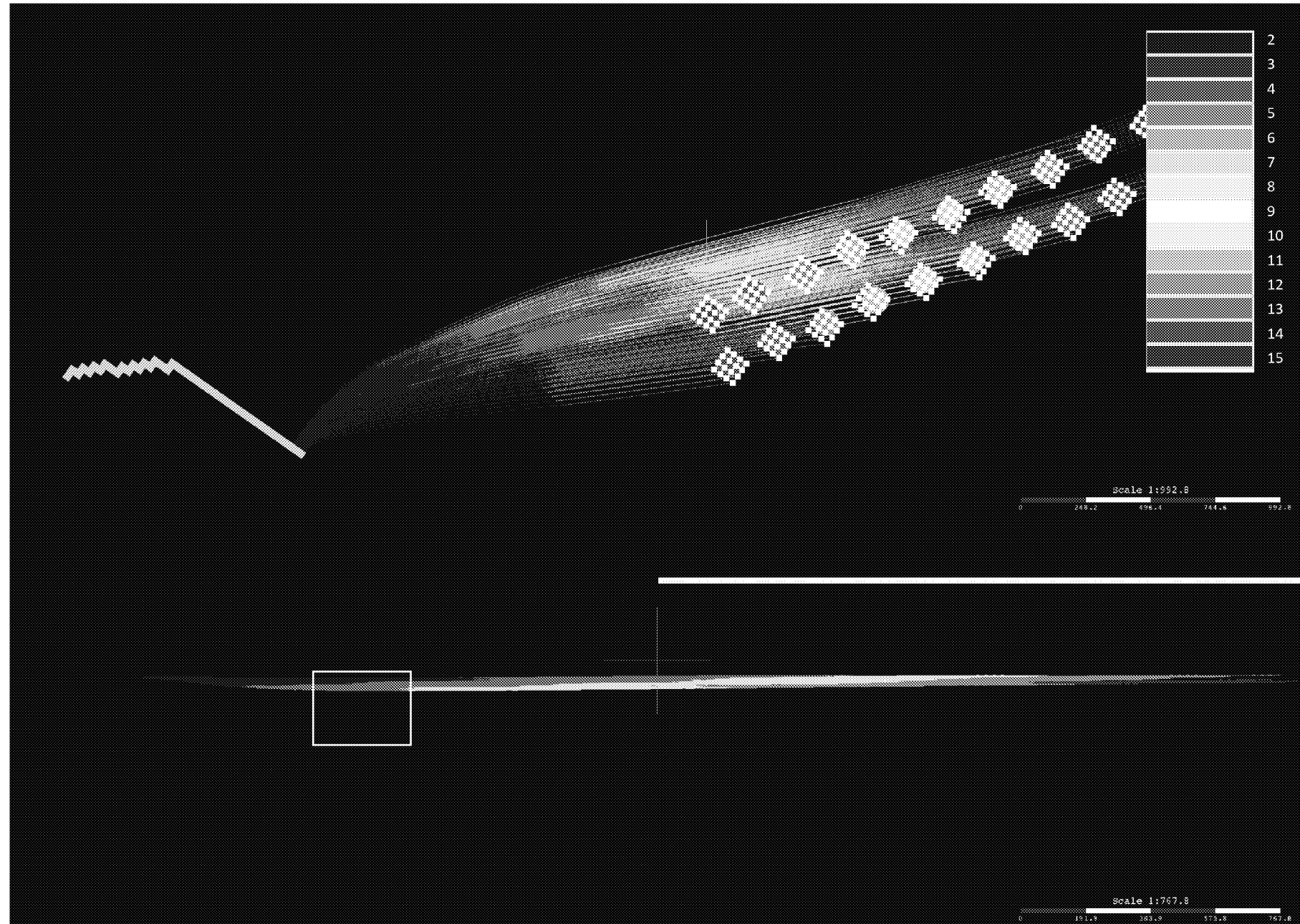
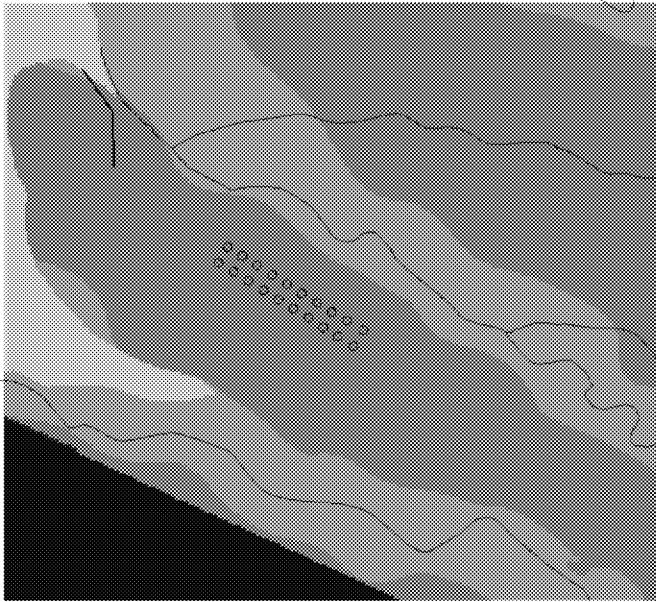
Three-Point Gradients (Observed vs.Simulate) at Triangle 4



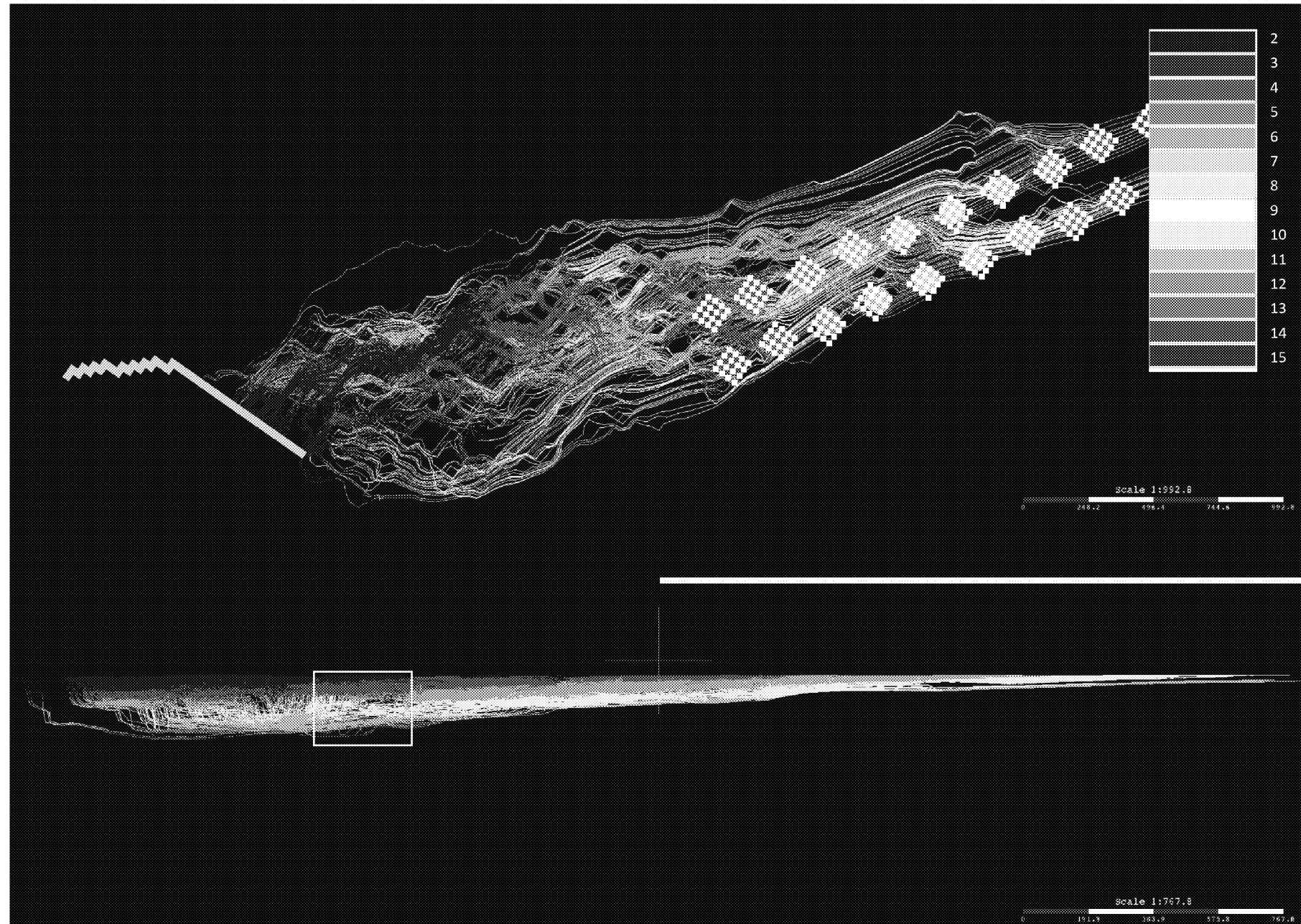
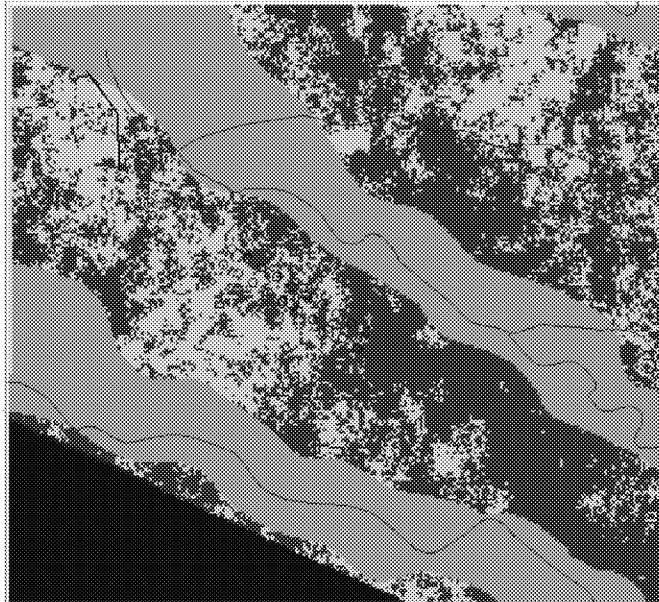
	Observed	Simulated
Number of Days	14	14
Minimum Azimuth	181.2	290.1
Maximum Azimuth	212.2	296.6
Minimum Magnitude	9.9e-05	1.5e-04
Maximum Magnitude	3.4e-04	3.5e-04



2. Forward particle tracking – w RHS, Homogeneous

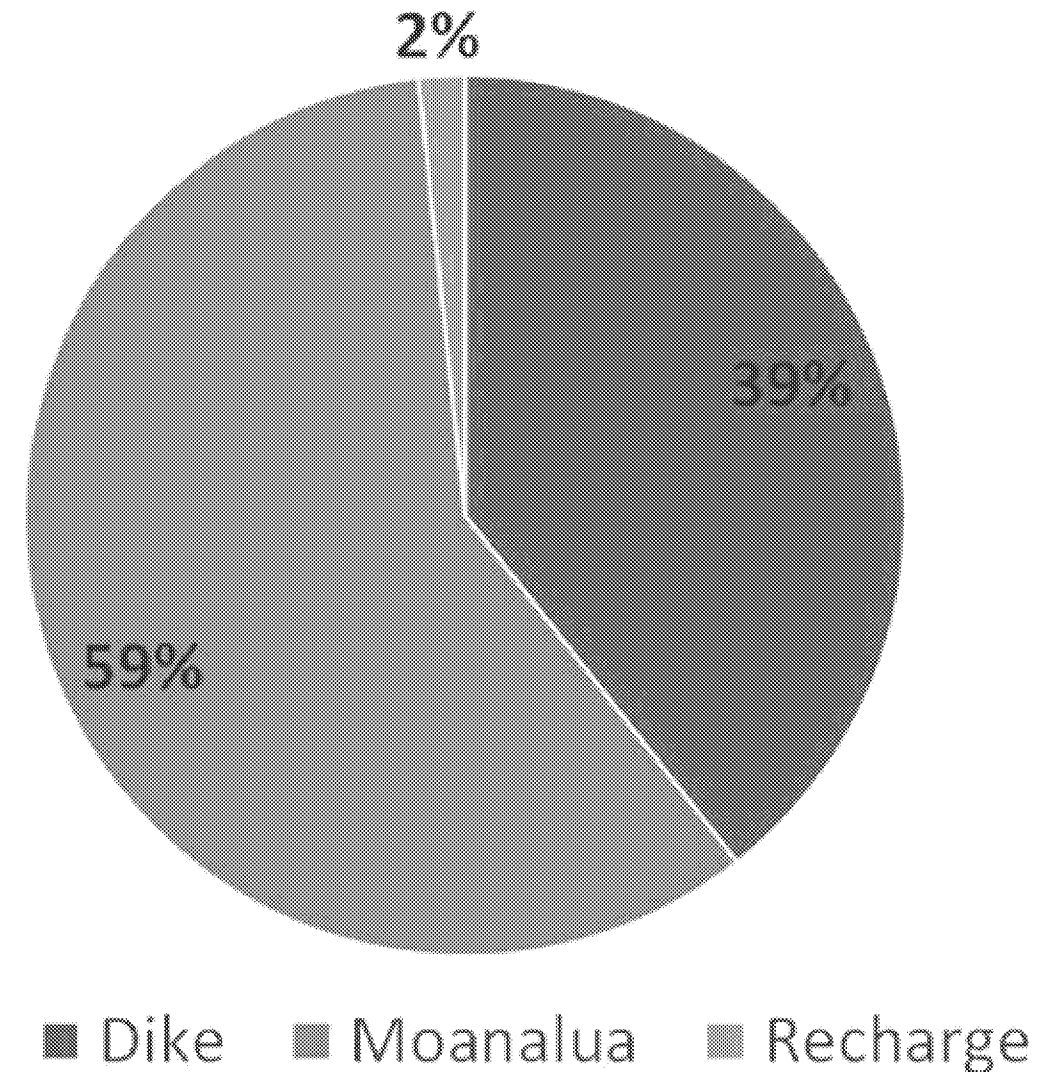


2. Forward particle tracking – w RHS, Heterogeneous



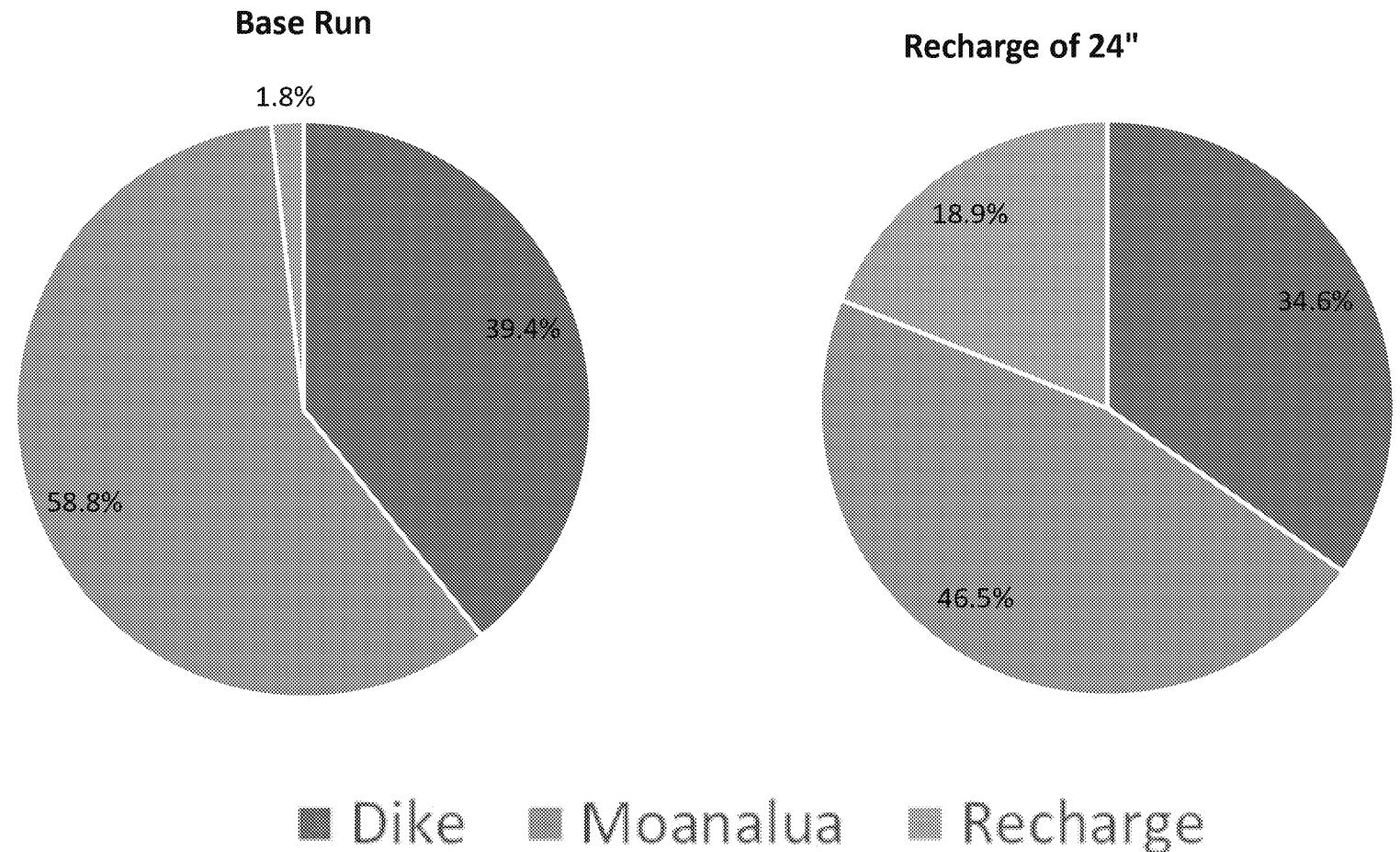
3. Unit source mixing: Contributions to RHS

- Calculated contributions to RHS of the various sources of water as shown
- In this scenario, inflow from Moanalua is dominant: this results from efforts to match the apparent WNW gradient direction indicated by water level data
- This scenario and graphic does not include “upwelling” as a source



3. Unit source mixing: Contributions to RHS

- Could placing bounds on influxes provide proportions that respect independent information on water budgets?



Discussion



Discussion

- Local-scale conditions can be evaluated using methods presented
- The potential to evaluate water quality data has been demonstrated:
 - Mixing analyses can help evaluate and calibrate conditions to independent geochemical analyses to verify flow fields and boundary conditions.
- Mixing analyses help evaluate sources of water to wells, and supplement water budget analyses:
 - Mixing calculations can be made using end-member concentrations. Examples have been developed by Bob Whittier (HDOH).
 - Contributions of water sources to RHS likely are not static over time.
 - Modeling of the capture zone developed by RHS should also reasonably match sources of water as developed through a mixing analysis.



Discussion

- The apparent RHBSF saddle: high Moanalua inflow or deep underflow match low-valued head-differences but are currently unverifiable.
- Compartmentalization: too much and heads don't correspond, too little and uniform flow ensues.
- Vertical flow: a plausible explanation for deeper brackish water at RHS, but it is unclear how this affects individual monitoring well locations.
- Although indicator kriging was used here, Transition Probability and Multi-Point geostatistical approaches, and random-walk stacking methods, were also considered.



Closing Remarks from Regulatory Agencies

